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Title of Invention: Perishable Product Electronic Label Including
Time and Temperature Measurement

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DESCRIPTION

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This application claims priority of Provisional Application Serial No. 60/419,695
filed October 17, 2002 and Provisional Application Serial No. 60/453,354 filed March 7,
2003, which are hereby incorporated by reference.

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BACKGROUND OF THE INVENTION

Field of the Invention

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Embodiments of the present invention relate generally to methods and apparatus
for detection of the conditions of spoilage of perishable merchandise. More particularly,
although not exclusively, these embodiments are concerned with the detection of
spoilage in chilled foodstuffs, such as meats.

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The monitoring and control of the condition of fresh foodstuffs, which have been
given enhanced, but not indefinite, shelf life by chilling and refrigerated storage, poses a
major problem in society. Thus the consumer demands fresh food, conveniently

packaged, and with all-the-year round availability in shops and supermarkets, while at the same time expecting that there is no danger of spoilage leading to impaired looks or flavor, or, more importantly, health risk in the purchased foods.

Oxidation and degradation by endogenous enzymes and bacterial growth

5 processes involving the metabolism of a wide range of food constituents, including carbohydrates and amino acids, can all contribute to losses in sensory and/or hygienic qualities of foods and their ultimate rejection by the consumer. The relative importance of these various spoilage processes may vary from product to product, with conditions of transportation and storage, with intended use etc., but the consequences of bacterial
10 growth are commonly an important contributory factor. This is especially the case for chilled-fresh foods such as meats.

Related Art

15 In reviewing the body of patents and commercial products, the inventors have found only chemical and visual means for monitoring the conditions of spoilage. None of the prior art known to the inventors revealed a similar method of providing the functionality of the present invention, and none incorporate a means whereby electronic and algorithmic apparatus and methods are used to indicate the spoilage of perishable
20 merchandise. The present invention utilizes electronic means to accomplish timing, and preferably not a chemical means.

SUMMARY OF THE INVENTION

The invention comprises, in a label for perishable items, an improvement comprising an electronic circuit including means for performing time-temperature
5 integration (TTI) and means for indicating that time and/or temperature levels have been reached that may compromise the quality or shelf life of the item to which the label is affixed. The label may be used on a wide variety of objects that require careful handling in terms of temperature and/or time elapsed before use. This may include fresh or frozen foods, meats, or even drugs, blood, and organs for organ transplant.
10 Preferably for food items, the labeling system includes circuitry that measures and calculates, and indicator(s) that signal that the time has come for discounted sale, and, later, that the time has come for disposal rather than sale. Optionally, the circuitry may include means, such as an “over-temperature alarm” system, to measure, calculate, and indicate when a one-time temperature violation has occurred that is of such a
15 magnitude that the item is immediately considered compromised or spoiled.

As an introduction to the problems solved by the present invention, consider the supply chain for the perishable food products industry from the point of preparation and packaging through distribution into retail locations to the point of purchase at the cash register. Along the supply chain, perishable food products are handled through various
20 temperature environments and over varying amounts of transportation, storage and shelf time. The spoilage of perishable food products can occur prior to purchase due to a variety of handling factors, where the temperature of these perishable food products may become compromised and/or elapsed time from packing to point of purchase may exceed safe limits.

There exists a need for a means whereby spoilage information can be conveyed to shippers, warehousemen, handlers, retailers and consumers of perishable products, so that informed decisions can be made regarding the freshness of products in the supply chain. The present invention provides such a means of detecting spoilage through
5 incorporation of one or several electronic timers and/or one or several temperature sensing and TTI calculation means into a portable, disposable label or similar package type, suitable to particular product applications.

In alternate embodiments, there can be simpler or more complex calculations for determining spoilage and/or indicating percentages, for example, to provide
10 advance warnings. Spoilage determination in different embodiments may be made strictly on a timer-only basis, or may be made using the TTI technique. For instances of the present invention where alternate timer-only vs. TTI capabilities are desired, mode selection input pins can be incorporated into the electronic timing and control integrated circuit. The indication of predetermined limits being exceeded can be
15 accomplished via a visual means, such as by utilizing LEDs or Liquid Crystal Displays (LCDs) or by audio means, such as by utilizing a piezoelectric sound element.

The present invention may take the form of a preferably-flexible, disposable label that is typically powered by a small battery. The label may include a label cover/casing that is typically attached to the outer surface of the perishable product
20 packaging using appropriate adhesives, or it may be placed in a visible pouch or attached by some other means to the target product to be monitored. Printed graphics on the top surface convey retail information such as unit pricing, weight, trademarks, logos, or other information.

A beneficial aspect of the present invention is that all of the circuitry may be incorporated into a custom integrated circuit, leading to a smaller, simpler circuit arrangement that requires less energy to operate than would otherwise be achievable. Reduced energy consumption allows reduced battery size, cost and weight.

5 An aspect of the present invention may involve a method of performing time-temperature integration entirely within an integrated circuit. Embodiments of such a method may comprise providing a temperature-variable oscillator or time-base, counting cycles of said oscillator within a logic circuit to determine when one or more preset total cycle counts is/are reached, and signaling when said total cycle count(s)
10 is/are reached. Such preset total cycle counts may be fixed in the circuit, or may be selected from a set of constants via I/O control, or may be adjusted at time of manufacture via program control. For instance, there may be a preset number of counts that signify 75% of life of product has occurred vs. a second, higher preset number of counts to indicate that 100% of life (spoilage) has occurred. Or, for embodiments of
15 the method employed in machinery or equipment operation, there may be preset numbers of counts that indicate different levels of hazardous conditions of prolonged high temperature operation.

 Therefore, the improvements made possible in the present invention are numerous, and are each of high value in terms of contribution to the invention's
20 benefits, features and usefulness. The full human benefit of this invention is not immediately fathomable, but industries that can apply it include shipping and product distribution, medicine, fresh baking and raw food products, meat, dairy products, poultry, fish and fresh produce. In each of these industries, human health and economic

benefits can be realized directly through the prevention of product spoilage. As well, industries that require machinery or equipment to remain within certain temperature limits can benefit from the invented apparatus and methods.

5 These aspects, associated embodiments, advantages and features of the present invention will be set forth in part in the description, and in part will come to those skilled in the art by reference to the following Detailed Description of the invention and referenced Drawings, or by practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a top view of one embodiment of the invention.

Figure 2 is an isometric view of the componentry of the preferred embodiment of the
5 invention, shown with layers separated for identification.

Figure 3a is a flowchart of the operation of the preferred embodiment of the invention.

Figure 3b is a flowchart of the operation of an alternate embodiment of the invention.

Figure 4 is a schematic diagram of the circuit of the preferred embodiment of the
invention.

10 Figure 5 is a schematic diagram of the circuit of an alternate embodiment of the
invention.

Figure 6 is a schematic diagram of a single-ended, three-stage ring oscillator circuit.

Figure 7 is a schematic diagram of a differential, three-stage ring oscillator circuit.

Figure 8 is a schematic diagram of a single stage of the differential ring oscillator
15 circuit of Figure 7.

Figure 9 is a schematic diagram of a delay tuning circuit utilizing temperature sensing
means.

Figure 10 is a schematic diagram of an alternate embodiment of a delay tuning circuit.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the Figures, there are shown several, but not the only, embodiments of the invention. A label according to one embodiment of the invention contains not
5 only printed information, but also an electronic circuit and indicators for the purpose of signaling to status conditions to those within view.

Figure 1 is a top view of one embodiment of the invention, which is a generally flat label for application to a product package (not shown). Surface 23 is intended to be both pre- and post-printed with text and graphics, as required for essential product
10 information, such as a description of the contents, pricing, bar-coding and other important information. Surface 23 is composed of paper, plastic or other printable material, and has openings, 1 and 2, through which light emitting diodes (LEDs) mounted underneath the surface can flash to alert those within view of the occurrence of a particular status condition. In the present invention, a status condition would
15 typically be one of a plurality of possible status conditions.

In alternate embodiments there may be a fewer or greater number of such LED's and openings, and there may be diffusion and/or color filters laminated to the backside of said openings. Activation tab 5 is the tip of a plastic insulator strip that, when pulled, comes out from between laminated layers of the label, thereby allowing a
20 battery contact to the circuit to be made.

Figure 2 is an isometric view of the componentry of the preferred embodiment of the invention, embodied in a perishable product label, shown with layers separated for identification. Top printable cover 23 is shown, with its openings 1 and 2. Contact

adhesive 22 adheres the cover 23 to printed circuit board 6. Similarly, adhesive surface 21 on bottom layer 9 adheres to the bottom of printed circuit board 6. Removable cover strip 10 is shown partially peeled away from bottom layer 9. Circuit board 6 is shown with an integrated circuit 7, two LED's 3 and 4, battery 8, and activation strip 5.

- 5 What is not illustrated in Figure 2 is a way in which the thicker components such as integrated circuit 7 and battery 8 can be prevented from protruding as unsightly bumps on the top or bottom surface of the label. A solution can be affected by inserting a die-cut foam adhesive material, such as 3M 4432 or 4416 double-sided adhesive foam tape as an alternative to adhesives 21 and/or 22. By die-cutting "wells" through the foam
- 10 material to accommodate the thicker components, the entire label ends up having a more consistent thickness across the top and bottom surfaces.

- Figure 3a is a flowchart of the operation of the preferred embodiment of the invention that operates using a time-temperature integration calculation method. At the Start 11 of the program flowchart, no action occurs until the battery activation tab is
- 15 pulled at step 12, which causes the counter to start counting at step 13. Once the counter reaches terminal count TC1 at condition 14, then indicator A begins flashing at 1 Hz at step 15. It will continue flashing until the counter reaches terminal count 2 at condition 16. Once terminal count TC2 is reached, then indicator A will stop flashing, and indicator B will begin flashing 17. Indicator B will then continue flashing until the
- 20 terminal count TC3 is reached 18, 19 and the program stops at flowchart step 20.

Figure 3b is a flowchart of the operation of an alternate embodiment of the invention that operates on a timer-only basis. At the start 110 of the program flowchart, no action occurs until the battery activation tab is pulled at step 120, which causes the

counter to start counting at step 130. Once the counter reaches its setpoint at condition 140, then indicator A begins flashing at 1 Hz at step 150. It will continue flashing until the counter reaches limit B at condition 170. Once limit B is reached, then indicator A will stop flashing, and indicator B will begin flashing at step 180. Indicator B will then
5 continue flashing until the battery runs out of energy at step 200 and the program stops at flowchart step 210. The duty cycle or on-time of the LED's can be varied, and shortening the LED duty cycle to fractions of a percent can extend battery life. The trade-off between battery life and light amplitude is subjective and dependent upon the type of LED and the type of battery used in the circuit.

10 Certainly, it is within the scope of this invention to include other program flow steps, such that the flashing of LED's occurs in different sequences. The duty cycle or on-time of the LED's can be varied, and shortening the LED duty cycle can extend battery life. Other indicator types, such as LCD types, may be substituted for LEDs. Audible piezoelectric beeper elements may be incorporated. Multiple timers and
15 multiple temperature sensors may be monitored in one label according to multiple embodiments of the present invention.

To realize lower energy requirement in the present invention, the persistence of vision property of the eye can be exploited by pulsing the LED on and off at a rate faster than approximately 25 Hz, resulting in lower total current drain for the same
20 apparent brightness, as opposed to when holding an LED On continually for the same desired viewing period. The trade-off between battery life and light amplitude is also subjective and dependent upon the, current limiting properties of the circuit and the type of LED and battery components that are used in the circuit.

Figure 4 is a schematic diagram of the circuit of the preferred embodiment of the invention. It shows battery 8 connected to activation switch 5, which supplies the Vbat voltage to the circuit. Oscillator 30 is astable, free-running and provides a clock signal to counter 31. The logic level outputs of counter 31 include terminal counts that occur at Terminal Count 1, TC1 (signal 32), Terminal Count 2, TC2 (signal 33), and Terminal Count 3, TC3 (signal 34), as well as a low duty cycle, 1 Hz clock Count, CNT (signal 35). The function of the two “D” type latches 36 and 37 is to register the terminal counts of TC1 (signal 32) and TC2 (signal 33), such that LED’s 3 and 4 are enabled to flash.

AND Gates 38 and 39 enable and disable flashing, according to what terminal counts have been registered. Note that TC2 (signal 33) disables green LED 3, and likewise TC3 (signal 34) disables red LED 4. Therefore until TC1 is reached, no indicator is flashing. Between the occurrence of TC1 and TC2, the green LED 3 is flashing, and between TC2 and TC3 the red LED 4 is flashing. In this preferred embodiment, after TC3 occurs, no LED is flashing. However, the red LED could flash until the end of battery life as a close alternate.

It is an object of the present invention to control the oscillator as a means of setting its base frequency through the function of tuning circuit 80. The interface 79 can be used to erase and write new values to tuning circuit 80. Also, the oscillator can be tuned in frequency relative to the local temperature through the function of temperature sensor 72. Detail of these control means is further described below.

Figure 5 is a schematic diagram of the circuit of an alternate embodiment of the invention. Upon closure of activation switch 5 by way of removal of insulating pull-

strip 47, the battery 8 supplies power, filtered by bypass capacitor 46 to microcontroller 41. Microcontroller 41, upon power-up, executes the program stored in program memory 40. Its instruction execution rate can be set by way of crystal 45, or the crystal can be eliminated through use of an internal RC oscillator, such as can be found in many modern microcontroller product offerings by companies such as MicroChip, Philips, Hitachi and others. The green and red LED's 3 and 4, are driven by output port pins on microcontroller 41.

As for temperature sensing means, thermistor sensor bridge 43 is amplified by instrument amplifier 44, from which the output signal is fed into the analog input of microcontroller 41. Using the elements described, changes in temperature affect the timing of events. Numerous temperature processing algorithms can be implemented and stored in program memory 40 for execution by microcontroller 41.

The circuit of Figure 5, through execution of the algorithm stored in program memory 40, can accomplish similar functions as is accomplished by discrete logic, such as the circuit of Figure 4, and according to the flowchart of Figure 3. The circuit of Figure 5 can also accomplish temperature compensation of the clock frequency, the emulation of tuning circuit 80 or any other appropriate algorithm, as required for alternate modes of operation. As will be described below, there is a specific formula that closely models the growth of pathogens that cause spoilage in perishable products.

The ring oscillator as shown in Figure 6 exemplifies a linear electronic circuit that typically contains three stages of single-ended phase shifters 50, 51 and 52, that are linked in a closed loop configuration. Each of these stages shift the phase of the signal by 120 degrees. The phase delay of each stage is affected through circuit loading by

resistors 53, 54 and 55 and capacitors 56, 57 and 58 in each respective stage.

A preferred type of ring oscillator is also three stage, but features differential phase shifting circuitry, as shown in Figure 7. Each phase shifting amplifier 59, 60 and 61 has cross-connected positive and negative inputs, and similar feedback to the circuit depicted in Figure 6. Frequency control input 66 can be adjusted, allowing a linear adjustment of phase in all three stages in parallel. Frequency shifting will occur proportional to the differential voltage level at the frequency control input 66. This renders this type of oscillator a Voltage Controlled Oscillator (VCO).

In the schematic diagram of Figure 8, a single differential stage of such a VCO is shown, which includes two complimentary CMOS driver transistor pairs, 62, 63 and 64, 65. In this circuit, the frequency control input (Vcont) 66 controls a current limiting circuit 67, which limits the tail current of the stage proportional to the level of Vcont signal 66.

It is an object of the present invention to decrease timeout periods, (of the terminal counts of counter 31 in Figure 4), in relation to the rate of spoilage of a product as temperature increases. To mirror the growth of pathogens, the oscillator frequency of the preferred embodiment varies according to $[f_{osc} = ne^{-(E_a/RT)}]$. This models the rate of reaction or Arrhenius Energy, where n is a constant, E_a is the activation energy, R is the universal gas constant, and T is the temperature in degrees Kelvin. Varying the timing of the present invention to achieve the desired equation with differing values of n can either be accomplished a) using timing algorithms and/or tables contained in program memory 40 and executed by microcontroller 41 of the

circuit depicted in Figure 5, or b) by varying the clock frequency over temperature by varying the control voltage of a VCO, thereby affecting the rate at which terminal counts are reached, in either case.

Figure 9 depicts a schematic of a delay tuning circuit suitable for control of the VCO of the preferred embodiment of the present invention. The current limiting circuit 67 is again depicted in Figure 9, where MOS transistor 80 regulates the current and phase of each ring oscillator stage. The frequency control 66 of each stage can be connected in parallel to current node 81, which will sink the oscillator tail current according to the output of amplifier 70. Note that node 66 is shown as the output of amplifier 70. This node is suitable for connection to Vcont in Figure 8.

Node 69 is a summing node that sums the signals from amplifier 71 and digital to analog converter (DAC) 71. Temperature sensor 72 affects the output voltage of amplifier 71. FLASH memory 73 can be overwritten by way of programming port 75 which can be connected to a programming device through interface 79. The memory 73 outputs a binary value to DAC 74, which in turn outputs a proportional analog signal level.

The function of the circuit depicted in Figure 9 is twofold. First, temperature at sensor 72 proportionally changes the oscillator frequency by way of changing the tail current of each stage of the oscillator. Second, the FLASH memory register 73 provides a means to tune the frequency of the oscillator.

An alternate embodiment depicted in Figure 10 provides a method of tuning the oscillator frequency. This circuit makes use of a FLASH memory register 73 to shift the polarity of a fixed set of capacitors 91, which in combination vary the capacitive

coupling between frequency control signal 66 and circuit ground proportional to their sum capacitance, thereby varying the oscillator frequency to achieve a calibrated frequency at time of manufacture.

When the output of a typical signal line (Q0-3) of memory register 73 is in a high state, (logic level “1”), then the stored charge on its respective capacitor is lower than when compared to when it is in the opposite, low state (logic level “0”).

The sum capacitive charges of all capacitors 91 serve to increase / decrease the loading of the oscillator 30 by varying the tail current. Rext is another load setting component that is summed to the load at node 66, and is intended to provide a coarse setting of tail current in the circuit.

Also connected to frequency control signal 66 is CMOS transistor 80, which is driven to conduct load current, thereby varying the oscillator frequency. The temperature sensor 72 is amplified by amplifier stage 71, which drives CMOS transistor 80.

The foregoing description of the present invention is not intended to be exhaustive or to limit the invention to the precise forms disclosed. For example, the following elements can be modified to achieve the same invention: Different amplifier configurations can be substituted for amplifiers 70 and 71 in Figure 9; Eliminating FLASH memory register 73, and instead directly driving I/O pins in order to directly tune the oscillator frequency can be practiced; The oscillator can be based upon, for example a crystal, can be silicon-based, or can be a ring-type oscillator, among numerous other basic types commonly known in the art; The temperature sensor can be

implemented using various transforming functions to suit different rates of reaction in the target product. The temperature sensor can be implemented using other sensing technologies such as thermistor, RTD or semiconductor junction types; Various indicators may be used, such as LCD's, e-ink, or similar display product offerings.

- 5 Many modifications and variations beyond the examples given will be apparent to practitioners skilled in this art.

Although this invention has been described above with reference to particular means materials and embodiments, it is to be understood that the invention is not limited to these disclosed particulars, but extends instead to all equivalents within the
10 broad scope of this Description, the Drawings, and the following Claims.